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Engaging the Brain

Implications of mobile EEG for spatial representation

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Abstract. We canvas issues in using neural imaging via EEG to map human responses to spaces. We describe the technology, some experiments by others relevant to architecture, and two of our own studies. One involves testing EEG as a supplement to user preference studies of urban typologies. The second involves recording the movement and affective (emotional) states of a pedestrian while moving through open spaces in Edinburgh. We produce map overlays of several such walkers as a method of mapping responses to urban spaces.

Keywords. neuroscience; EEG; emotiv; architecture; affect.

Introduction

Brain imaging technologies such as electroencephalography (EEG) were once confined to hospitals and specialised laboratories. Now EEG is available as a low-cost peripheral attached to a laptop computer, encouraging its use in many research contexts outside of the clinic. EEG measures faint electrical impulses from sensors positioned on the surface of a person's scalp. Such devices are wireless, easy to wear, and can be interfaced with other computer applications. More sophisticated brain-imaging techniques such as fMRI (functional magnetic resonance imaging) offer greater temporal and spatial resolution, but their operations are physically constraining. EEG is used increasingly for developing insights into the neural basis of human (and animal) cognitive responses to stimuli, situations and environments. Software has been developed that translates EEG data into commonly understood emotional parameters (such as boredom and excitement) raising the profile of affect, mood and emotion in understanding human responses to places.

We are currently undertaking a study in which we present human subjects with images of settings with varying degrees of urbanity (ie green, built, green-built). The study examines the relationships between self-reported image preferences and EEG responses. Subject responses are monitored through both EEG and eye tracking. We will report in detail on the study outcome elsewhere. In conjunction with that study we are undertaking a series of speculative projects directed to design and place. These include using GPS to geo-annotate EEG responses while participants move through the urban environment, the main outcome described in this paper.

Mapping the EEG readings of someone as they wander through an outdoor space provides a new kind of sensory mapping, especially when maps from different pedestrians and at different times are laid over each other. The emotional state of any pedestrian is of course influenced by many factors apart from the physical environment. Devices and algorithms mediate such readings. We have found that legible EEG maps provoke users to disclose interesting narratives and discourses about the places they have just visited, all the more so when the map puts a claim on presenting the private feelings of the person telling the story. At the very least, such maps support, disrupt, and yield unexpected insights into a place, supplementing other modes of observation and analysis.

Our studies also confirm high levels of emotional arousal in anticipation of a visual stimulus, as when waiting for an image of a landscape to appear on a video screen. This lends support to the proposition advanced in phenomenology that much of our spatial experience is guided by expectations. We are investigating this insight as an offshoot of our empirical study.

In what follows we present an overview of the EEG technology relevant to this kind of perceptual-spatial study. We explore emotion and affect as major components of human experience in the environment (virtual, natural or man-made) and how mobile EEG technology allows us to study these relationships in new ways.

Reading the brain

Detecting and recording brain activity has spawned new areas of research in domains such as brain computer interfaces (BCI), affective computing (Picard, 1998), the gaming industry, e-learning, interaction design, and even market research. Direct information about the emotional state, or the "cognitive load," of the user offers researchers and designers a means of gauging people's responses to stimuli (games, products, commercials, designs) and implement feedback strategies. Various fields are picking up on this opportunity, notably prosthetics and medicine, but also marketing, social sciences, the performing arts and more recently architecture. The website of the Academy of Neuroscience for Architecture established in 2003 asserts boldly: "Not only will architects benefit from the knowledge base made possible by neuroscience, but future generations of school children, hospital patients, office workers, and worshippers in sacred places will have their environments more carefully tuned to their needs and desires" [1]. The mobile nature of new commercial EEG systems revives interest in the way people respond to and value the spaces and environments they inhabit and through which they move, perhaps adding a new dimension of Donna Haraway's invisibly wired "cyborg citizen" (Haraway, 1991).

The effort to reveal and understand brain processes dates back to the end of the nineteenth century when scientists studied electric activity in the brain and had begun to identify the functional role of brain cortices. The techniques to amplify and record the faint electrical impulses generated by neuronal activity from sensors positioned on the surface of the scalp was finally established in 1929 by the psychiatrist Hans Berger (Swartz et al, 1998). EEG does not detect individual nerve signals, but the overall rhythm by which impulses propagate through the neural system (Ramachandran, 2011). Brain waves are measured according to (i) amplitude, usually 10-100 mV (microvolts), and (ii) frequency, ranging from 1-80Hz. EEG waves are classified into several frequency bands: *alpha, beta, gamma, delta, theta* and *mu.* These bands are independent of each other and are generally mapped to specific brain and mental states. For example, higher values of alpha band (8-12Hz) are apparently an indication of low brain activity typical of a relaxed mental state; beta band waves (12-30Hz) on the other hand, are dominant during an active, alert state of mind. So we would expect such readings to indicate something about a person's mood as she moves through a space.

Direct brain computer interfaces (BCI) present the most conspicuous challenge. BCI provides "a communication system in which messages or commands that an individual sends to the external world do not pass through the brain's normal output pathways of peripheral nerves and muscles" (Wolpaw et al, 2002). A BCI system translates EEG signals into specific messages or commands to allow the user to communicate or control devices directly: such as a computer, word processor or speech synthesizer, and even a drawing or CAD system. Demonstration software that accompanies the Emotiv EPOC EEG system offers a tutorial in this kind of control (as if manipulating a model of a cube by "thought" alone) mastered only with great difficult, indicating how far such techniques are from everyday use.

Initially, BCI frameworks were developed to enable people with neuromuscular disabilities to communicate or act. Their use in ameliorating mobility impairment in certain individuals receives substantial press coverage. The capacity of such systems to translate brain activity into useful information gained prominence as a method of understanding user experience in a range of biofeedback applications and research protocols. The main advantage of EEG over other measures such as GSR (galvanic skin response) is that it enables researchers to identify which brain regions are activated and their role in behaviour.

Commercial EEG

We selected the Emotiv EPOC EEG device for our research. It consists of 14 sensors that take readings from activation sites on the surface of the brain, and comes with a suite of software packages. It also includes a 2-axis gyroscope to detect the wearer's head motion and orientation. Three software packages are available. (i) The "Expressiv Suite" records and filters raw EEG data and detects facial expressions. (ii) The "Cognitiv Suite" anticipates the wearer's intentional movements, and (iii) the "Affectiv Suite" delivers parameters indicating emotional states: **excitement**, **frustration**, **engagement**, and **meditation** (figure 1).

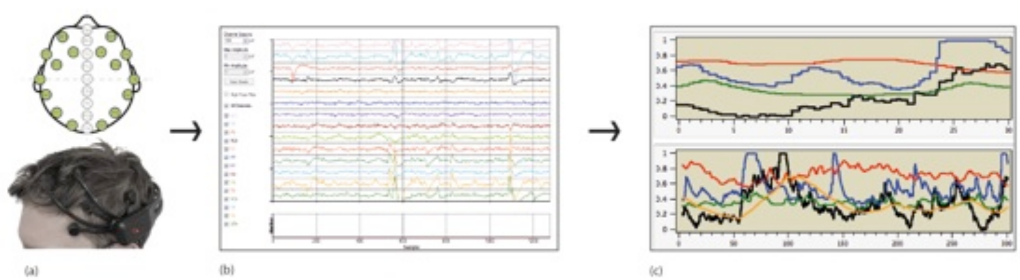

Figure 1 *Emotiv EPOC records EEG signals from 14 sensors position according to the 10-20 International System. Raw EEG signals are then 'translated' and classified in four different emotional states. (b) Output from Emotiv Testbench software; (c) output from Emotiv Control Panel and 'Affective suite' (EEG data belongs to the authors.)*

The Emotiv EPOC EEG system was designed for testing video games and for designing games that respond in some way to the emotional states of the player. It is purposed to enhance visual stimulation and screen based experiences, such as watching images, films or playing a computer game. It also delivers raw EEG signal output. Most EEG processing platforms (BCI2000, EEGlab and OpenVibe) have software libraries to integrate EPOC in neuroscientific studies. A number of academic studies have confirmed the reliability of the Emotiv's indications of emotional states (Cernea et al, 2011). The technology is relevant to a range of screen based research protocols applicable to the humanities, including architecture.

Emotion and behaviour

The advent of such affective technologies brings again into relief the source, the role and the interrelationships of the emotions in our experience of space. The debate about the nature, the structure and the taxonomy of emotions is controversial (Russell, 2009). Neuropsychologist Antonio Damasio established the vital role of emotional states in cognitive processes such as reasoning and decision making (Damasio, 2006). Affect also constitutes a major component in social behaviour, notably in theories about empathy (Rizzolatti et al, 2004). Based on evidence from studies on the behavioural changes of patients suffering from frontal and prefrontal brain lesions (the brain regions central to emotional activity, together with the limbic system), Damasio advocated the "somatic marker hypothesis" arguing that emotions enable us to make decisions favouring choices similar to those already made under similar circumstances.

Evidence from studies in human behaviour "suggests that emotion as well as rational cognition is a major influence on negotiating behaviour, especially when [commercial] offers are considered to be unfair" (Lee et al, 2007). Neuromarketing is established on the basis of such findings (Page, 2012). As Lee et al explain, neuromarketing does not attempt to predict or control people's behaviour; an argument at the basis of common moral and ethical concerns about this emerging discipline. They argue that the aim is to understand the neural basis of preference, market behaviour, consumer choice-making, brand trust, pricing, negotiation and even to redefine marketing ethics.

The main advantage of EEG over other measures such as GSR is that it enables researchers to identify which brain regions are activated and their role in behaviour. Lee et al explain the neural basis of preference. For example, studies show that "it seems likely that the price of a basic product such as sugar is very different in nature from the price of a conspicuous product such as a Nike sports shoe, or a Porsche sports car, which should be evidenced in changes in the location of brain activity when these prices are viewed alongside their associations" (Lee et al, 2007, p. 202).

Affect and architecture

EEG processing brings to the foreground the relationship between affect and emotion, and their relationship to the phenomenological idea of "mood." According to neurophysiologist J. Russell, emotions are episodic, relevant and oriented towards an agent, object or event. On the other hand, there is an underlying and pervasive element that he describes as *core affect*: "that neurophysiological state consciously accessible as the simplest raw (nonreflective) feelings evident in moods and emotions" (Russell, 2003, p. 148). In phenomenological terms a *mood* is a pervasive condition that is neither collective nor individual, and is a necessary prerequisite for anyone to *have* an emotion

(Heidegger, 1962). The strong conjecture is that mood associates with place and to a participative community as much as it resides with the "internal" mental condition of solitary human agents.

Affect is of interest in architectural discourse. Theories about affect provide insights into how environments (physical or virtual) evoke emotional responses in a viewer or user: how people engage with spaces and their attributes, and what those spaces offer for action. EEG-based assessment of preferences and behaviours in architectural, urban and other spaces could contribute to more effective design, policy making, and the creation of spaces that contribute positively to people's mood and health (Roe et al, 2011).

Mobile EEG provides non-invasive methods of capturing the affective states of people as they occupy environments. EEG studies indicate how people evaluate architectural designs, visualise, navigate and develop spatial cognition. Virtual reality has been used to recreate spatial experience within a controlled environment. Architectural researchers Balakrishnan et al established a methodology to evaluate affect and "the experiential aspects of architecture by bringing psychophysiological measures into the realm of 3-dimensional visualization — more specifically, virtual reality" (Balakrishnan et al, 2006). Their framework combined measurements of electrodermal activity (EDA) and facial expression to gauge immersion and presence. Edelstein et al used hi-density EEG to study neural activity during navigation in an ambiguous environment (Edelstein et al, 2008; Champion et al, 2011).

Mapping affect

As well as mapping where things happen in the human brain, researchers have paid attention to the difficult task of mapping the affective states of human beings as they encounter places. Creating a cartographic map of affect can be both an intimately personal and a shared, collective process. For the architect James Corner, the agency of such a mapping "lies in neither reproduction nor imposition but rather in uncovering realities previously unseen or unimagined, even across seemingly exhausted grounds" (Corner, 1999). Eric Fischer's maps of cities that emerge from the traces of geoannotated photographs uploaded on FlickR [2] tell a powerful story of urban dynamics, delineating the paths of tourists and locals, but also tell the story of the urban affect; what was photographed and what was left unnoticed. The communicative power of such grassroots cartographies to articulate a view of the *urban* through the aggregation of traces brings to mind Brian Massumi's plea to "look only at the movements – and they will bring you to matter" (Massumi, 2002), and Michel de Certeau's theory about the agency of walking (and in general of urban mobility) to demarcate spatial and social conditions (de Certeau, 1984). Mapping the city emerges as a kind of conversation among communities, cartographers, interpreters and the spatial phenomena as experienced.

Easily accessible GPS provides a further tool for mapping. The artist Esther Polak created a map of Amsterdam that was traced solely by the movement of a few of its inhabitants [3]. The artist Christian Nold equipped citizens with GPS-enabled galvanic skin response (GSR) sensors to map arousal levels in their neighbourhoods (Nold, 2009). In an effort to further explore the collective patterns of affect and to study wellbeing in the UK, the economist George MacKerron created Mappiness, a smartphone application to conduct crowd-sourced research [4]. The aim of Mappiness is to explore the "geography of emotions" in the UK by asking its users at frequent daily intervals to report “how you’re feeling,” and to provide information about their location, activity, group, and situation, thereby creating an extensive geographical survey of the affective experience of a large number of individuals. These examples showcase opportunities for research methodologies and resources, cartographic relevance, scalability and the mobility of participants, together with a significant interest in the affective dimensions of the city. We draw on such studies in our own research into affective mapping.

Sensing technologies provide new avenues for experimentation. The artist Leah Heiss has employed affective “wearables” to engage two users in a remote “conversation” as the one user sends heart rate signals to the other, using vibrations on their clothing (Heiss, 2006). Experimental projects such as these suggest novel ways to engage technology in creative practice, and to create new architectural and sensory experiences. One of us (Panagiotis Mavros) was involved in an electro-acoustic performance in which a saxophonist wearing the EEG headset would pause from playing and induce emotional states in himself in order to influence the way the sounds were modulated by software.

In an effort to understand an urban or architectural space, architectural designers often record and sketch information and impressions, mapping features of spaces, registering variables such as street traffic, materials and colours, sounds and smells. It is now possible to add an affective dimension. This can involve a research by design protocol, where the outcome of such a process is open ended, activates a creative conversation with and spatial appropriation of space, through design, as a means to generating information. Mapping the emotional states of one or more users can support and disrupt, yielding unexpected insight into a place, or confirm intuitive observations about behaviour. Such approaches also draw on ethnographic research, as participants of such studies talk through their wanderings, explaining or speculating on the motives behind their recorded emotional states. Adding a numerical EEG dimension to a designer’s “mental maps” (Lynch, 1960) has the potential to enhance our understanding of navigation and behaviour in urban environments.

Edinburgh and the brain

We established two experimental studies to explore the innovative affordances of EEG technology in the domain of architecture and urbanism. As already indicated, our first study aimed to validate the use of Emotiv EPOC for environmental preference studies. In our test a total of twenty participants were asked each to observe a sequence of images of urban and natural environments on a computer screen (figure 2). We used Emotiv EPOC to register their affective responses together with the simultaneous recording of their gaze using eye tracking. Information relating to pupil diameter, for instance, can also indicate affective state. The images depict various urban and natural environments that have already been rated for affect (arousal and valence) from a previous study (Whyte et al, 2010). The objective affective data from EEG was compared with the subjective ratings of participants, to establish whether the data reliably correlated. Others have used a similar procedure (without EEG) to support arousal-valence theory (Russell et al, 1980).

Our second study targeted the deployment of EEG in urban spaces, exploring ways of using this technology in the assessment of urban experience.

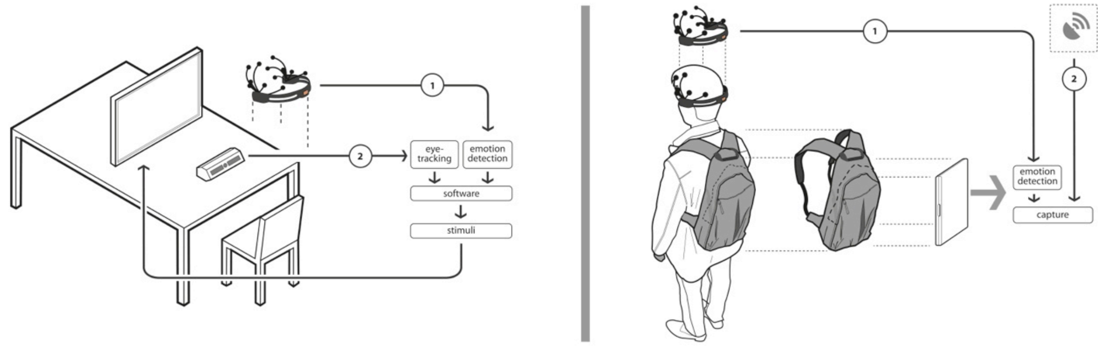

Figure 2 Left: A visual stimulus arrangement: EEG data (1) and eye tracking data (2) are combined to evaluate participants' responses to images. Right: Diagram of the experiment gear. Emotiv EPOC's data (1) are geoannotated by a GPS unit (2) and stored on a laptop.

The aim of the experiment is to validate this framework for assessing affect in diverse outdoor environments. The uncontrolled nature of such an experimental protocol poses important challenges, both in the experiment setup and in data analysis. The experiment involved a light, high performing laptop with solid state storage, wireless EEG and a GPS unit. We developed a custom software platform to geoannotate emotional states from Emotiv's *Affective Suite*, and conducted a series of exploratory outdoor studies (figures 2 and 3).

Figure 3 Participants walk through Edinburgh wearing an Emotiv EPOC, and then they describe and reflect on their experience, noting moments of interest or identifying the affective elements of their route.

The experience of one participant reveals overall tendencies (figure 4b), in terms of excitement (i) and frustration (ii) levels — graph (iii) shows excitement levels smoothed by Emotiv's software. At first inspection, emotional levels plotted as charts (figure 4b-top) and as maps (according to their geographic location, figure 4b-below) reveals basic patterns of emotional activity. The participant remains excited in section 1-2 which is full of social interaction, while excitement drops in section 2-3 walking through the park. The reverse pattern is evident in frustration levels, which according to our observation does not only reveal a negative response, but also more intense thinking and a self-reflexive state. An aggregate map of excitement levels of three participants (figure 5c: peaks are in red, blue and yellow respectively) reveals shared patters of emotional activity, even though the experiment was performed on different days.

Discussion

The aim of this paper was to discuss how the emergence of affordable and mobile EEG devices offers new opportunities to measure subjective experience and to understand the neural basis of human behaviour in architectural and urban contexts. Arguably, this is a prominent field, encouraging interdisciplinary research among architects, planners, psychologists and neuroscientists.

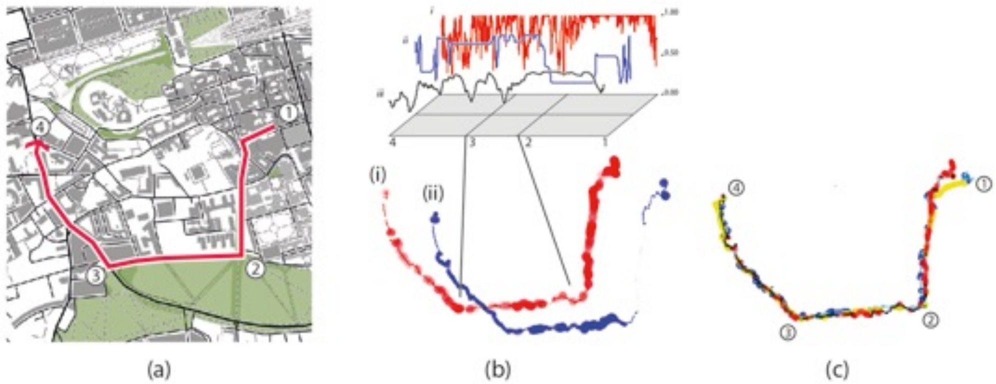

Figure 4 (a) Map of the route in central Edinburgh. (b) Emotional activity of one participant during the route, in charts (above) and plot in space (below). (c) Aggregate of excitement levels from three participants.

We wanted to develop and test a framework to explore if commercial EEG equipment and commercial EEG based emotion detection software can be used in scientific research, specifically in relation to questions related to architectural and urban research. So far our studies reveal the feasibility of such an endeavour and the locative relevance of emotional activity among individuals. Further research is necessary to study affective experience in relation to place and urban behaviour. Our studies also reveal the high degree of neural activity exhibited by human subjects in anticipation of some spatial experience. Talking with subjects about their recorded affective response elicits compelling insights into their experience and a high degree of self questioning and probing: why did I respond like that to this image or this location?

Our research also brings into relief questions of embodiment. The psychologist William James challenged the usual (and Cartesian) understanding that stimuli in the environment compel us to feel a particular emotion, which then results in some bodily response, such as running away in fright, suggesting that our bodily activity is complicit in affective experience (James, 1884). Based on evidence from neuroscience, the theories of embodied and extended mind argue for the synergy of the mind, brain, body and environment in cognitive processes and emotions (Clark, 1997; Coyne, 2007). Architecture configures spaces not just to “convey meaning,” as containers for cognitive agents (people), embodying ideas, or to help us think better, but spaces are actively *complicit* in thought. The use of mobile EEG opens the possibility of exploring these questions, providing alternative models for mapping cities and environments, new approaches to interaction design, and new ways of understanding social activity and human behaviour in context.

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